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Attorney Docket No. 826.1633D

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:

Shinya INAGAKI, et al.

Application No.: 10/823,634 Group Art Unit: 2874

Filed: April 14, 2004 Examiner: Jennifer Doan

For: APPARATUS AND METHOD OF COMPENSATING FOR WAVELENGTH DISPERSION OF OPTICAL TRANSMISSION LINE

SUBMISSION OF VERIFIED ENGLISH TRANSLATION OF FOREIGN PRIORITY DOCUMENT

Commissioner for Patents
PO Box 1450
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Sir:

Applicants submit herewith a verified English translation of the following foreign application to which foreign priority has been claimed:

Japanese Patent Application No. 2000-002655
Filed: January 11, 2000

If any further fees are required in connection with the filing of this submission, please charge such fees to our Deposit Account No. 19-3935.

Respectfully submitted,

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VERIFICATION

I, Hanae SASADA, residing at Hyogo, Japan, state: that I know well both the Japanese and English languages; that I translated, from Japanese into English, the priority document as filed in the U.S. Patent Application No. 10/823,634, filed on April 14, 2004 as a divisional application of prior application No. 09/753,573, filed on January 4, 2001; and that the attached English translation is a true and accurate translation to the best of my knowledge and belief.

Dated: October 19, 2006

Hanae Sasada.
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[Document Name]	Patent Application
[Reference No.]	9902487
[Filing Date]	January 11, 2000
[Addressee]	Commissioner, Patent Office
[Int'l Patent Classification]	H04J 14/02 H04B 10/18
[Title of Invention]	Dispersion Compensation Apparatus and Method
[Number of Claims]	9
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[Fee Designation]	
[Pre-payment Reg. No.]	012542
[Payment Amount]	JPY21,000
[Index of Submitted Article]	
[Article Name]	Specification 1
[Article Name]	Drawings 1
[Article Name]	Abstract 1
[General Power of Attorney No.]	9705047
[Necessity of Proof]	Yes

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[Document Name] Specification

[Title of the Invention] DISPERSION COMPENSATION APPARATUS AND METHOD

[What is Claimed is:]

1. A dispersion compensation apparatus which compensates for wavelength dispersion of an optical transmission line, comprising:

first compensation means for compensating for dispersion slope of input light, the first compensation means having a wavelength dispersion characteristic dependent on wavelength; and

second compensation means for compensating for wavelength dispersion of the input light, the second compensation means having a constant wavelength dispersion characteristic over a plurality of wavelengths.

2. A dispersion compensation apparatus which compensates for wavelength dispersion of an optical transmission line, comprising:

first compensation means for compensating for dispersion slope of input light, the first compensation means having a wavelength dispersion characteristic dependent on wavelength; and

second compensation means for compensating for wavelength dispersion of the input light, the second compensation means having a variable wavelength dispersion characteristic.

3. A dispersion compensation apparatus which compensates for wavelength dispersion of an optical transmission line, comprising:

fiber type compensation means for compensating for wavelength dispersion and dispersion slope of input light; and

virtually imaged phased array (VIPA) type compensation means for compensating for a sum of the wavelength dispersion of the input light and the wavelength dispersion of the fiber type compensation means.

4. An apparatus as in claim 3, wherein said sum of the wavelength dispersion of the input light and the wavelength dispersion of the fiber type compensation means indicates negative wavelength dispersion, and the VIPA type compensation means has positive wavelength dispersion which cancels at least a part of the negative wavelength dispersion.

5. An optical transmission system comprising:

transmission line means for transmitting light;

first compensation means for compensating for dispersion slope of the transmission line means, the first compensation means having a wavelength dispersion characteristic dependent on wavelength; and

second compensation means for compensating for wavelength dispersion of the transmission line means, the second compensation means having a constant wavelength dispersion characteristic over a plurality of wavelengths.

6. An optical transmission system comprising:

transmission line means for transmitting light;

first compensation means for compensating for dispersion slope of the transmission line means, the first compensation means having a wavelength dispersion characteristic dependent on wavelength; and

second compensation means for compensating for wavelength dispersion of the transmission line means, the second compensation means having a variable wavelength dispersion characteristic.

7. A system as in claim 5 or 6, comprising one or a plurality of said first compensation means, said second compensation means being on a reception device side.

8. A dispersion compensation method for compensating for wavelength dispersion of an optical transmission line, comprising:

transmitting signal light to travel through the optical transmission line;

compensating for dispersion slope of the signal light

using a wavelength dispersion characteristic dependent on wavelength; and

compensating for wavelength dispersion of the signal light using a constant wavelength dispersion characteristic over a plurality of wavelengths.

9. A dispersion compensation method for compensating for wavelength dispersion of an optical transmission line, comprising:

transmitting signal light to travel through the optical transmission line;

compensating for dispersion slope of the signal light using a wavelength dispersion characteristic dependent on wavelength; and

compensating for wavelength dispersion of the signal light using a variable wavelength dispersion characteristic.

[Detailed Explanation of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a dispersion compensation apparatus and method for compensating for the wavelength dispersion of an optical fiber in a wavelength division multiplexing (WDM) optical transmission system.

[0002]

[Prior Art Technology and Problems to be Solved by the Invention]

In a conventional WDM optical transmission system, a fiber-type dispersion compensator referred to as a dispersion compensation fiber (DCF) is well known as a technology of compensating for the wavelength dispersion of a line fiber forming an optical transmission line. A DCF indicates dispersion having a sign inverse to that of the line fiber, and can thereby compensate for the dispersion of the line fiber. Since the amount of compensation provided by a DCF is proportional to the fiber length of the DCF, it is necessary to adjust the fiber length of the DCF depending on the dispersion

of a target line fiber.

[0003]

DCFs are produced by manufacturers at intervals of a fixed, specific amount of dispersion (for example, 100 ps/nm). Unfortunately, the actual amount of dispersion of a line fiber is typically not an even multiple of these intervals, thereby causing a setting error of the amount of compensation. As a result, it is very difficult to completely compensate for the wavelength dispersion of a line fiber using DCFs currently available on the market.

[0004]

Furthermore, wavelength dispersion of a line fiber is wavelength-dependent, and is known to have a characteristic referred to as a dispersion slope. The dispersion slope corresponds to the inclination of the dispersion-to-wavelength graph linear-approximated in a wavelength area used for a signal light.

[0005]

A DCF has a dispersion slope having a sign inverse to that of a line fiber. Based on this, the dispersion slope of the line fiber can be partially compensated for. However, since the dispersion slope of the DCF is proportional to the fiber length, both wavelength dispersion and dispersion slope of the line fiber cannot be compensated for using a DCF of a fixed length.

[0006]

It is an object of the present invention to provide a dispersion compensation apparatus and method for compensating for wavelength dispersion and dispersion slope of a line fiber, and for reducing the setting error of the amount of the compensation of wavelength dispersion in a WDM optical transmission system.

[0007]

[Means for Solving the Problems]

FIG. 1 shows a principle of a dispersion compensation

apparatus according to the present invention. The dispersion compensation apparatus shown in FIG. 1 comprises compensation means 1 and 2, and compensates for the wavelength dispersion of an optical transmission line such as a line fiber.

[0008]

According to the first aspect of the present invention, the compensation means 1 has the wavelength dispersion characteristic depending on a wavelength, and compensates for the dispersion slope of input light. The compensation means 2 has a constant wavelength dispersion characteristic for a plurality of wavelengths, and compensates for the wavelength dispersion of the input light.

[0009]

The compensation means 1 is, for example, a fiber type compensator such as a DCF, has a characteristic of a dispersion slope, etc. depending on a wavelength, and cancels the dispersion slope of the input light. The compensation means 2 has a constant wavelength dispersion characteristic for a plurality of different wavelengths contained in a wavelength area for which the compensation means 1 compensates, and cancels the remaining wavelength dispersion when the wavelength dispersion obtained by summing the wavelength dispersion of the input light and the wavelength dispersion of the compensation means 1 does not indicate zero.

[0010]

With the above-described configuration, the wavelength dispersion and the dispersion slope of a line fiber can be simultaneously compensated for, and the setting error of the amount of compensation can be reduced if the wavelength dispersion of the compensation means 2 indicates an appropriate value.

[0011]

According to the second aspect of the present invention, the compensation means 1 has a wavelength dispersion characteristic depending on a wavelength, and compensates for

the dispersion slope of input light. The compensation means 2 has a variable wavelength dispersion characteristic, and compensates for the wavelength dispersion of the input light.

[0012]

The compensation means 1 performs an operation similar to the operation according to the first aspect. When the wavelength dispersion obtained by summing the wavelength dispersion of the input light and the wavelength dispersion of the compensation means 1 does not indicate zero, the wavelength dispersion of the compensation means 2 is appropriately adjusted, and the remaining wavelength dispersion is canceled.

[0013]

With this configuration, the wavelength dispersion and the dispersion slope of a line fiber can be simultaneously compensated for, and the setting error of the amount of compensation can be reduced if the wavelength dispersion of the compensation means 2 can be adjusted to an appropriate value.

[0014]

For example, the compensation means 1 shown in FIG. 1 corresponds to a DCF 93 shown in FIG. 9 and a DCF 132 shown in FIG. 12, which will be described later, and the compensation means 2 shown in FIG. 1 corresponds to a virtually imaged phased array type compensator 92 shown in FIG. 9 and a virtually imaged phased array type compensator 133 shown in FIG. 12.

[0015]

[Preferred Embodiments]

Reference will now be made in detail to the present preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings.

According to embodiments of the present invention, the dispersion slope and the wavelength dispersion are simultaneously compensated for by combining the first compensator mainly for compensating for a dispersion slope with the second compensator mainly for compensating for wavelength dispersion.

[0016]

As the first compensator, for example, the above mentioned fiber type compensator is used. As the second compensator, for example, a virtually imaged phased array (VIPA) type compensator is used.

[0017]

A VIPA is an optical branching filter capable of generating a large angular dispersion from input light, and a VIPA type compensator using the branching filter can generate a wide range of positive and negative wavelength dispersion.

[0018]

A VIPA is described in detail in "Wavelength Branching Filter," Japanese Patent Application Laid-Open 09-043057. A VIPA type compensator is described in detail in (a) "Optical Device using Virtually Imaged Phased Array for Generating Chromatic Dispersion," Japanese Patent Application 10-534450, and International Publication Number for PCT Application WO98/35259; (b) "Optical Device using VIPA for Chromatic Dispersion," Japanese Patent Application 11-513133, and International Publication Number for PCT Application WO99/09448; and (c) "Chromatic Dispersion Compensation Using Virtually Imaged Phased Array," M. Shirasaki, Optical Amplifiers and Their Applications, Paper PDP-8, July 1997.

[0019]

FIG. 2 shows an example of a VIPA. The VIPA shown in FIG. 2 comprises a cylindrical lens 11, and a glass plate 12 having the thickness of t. Reflection coatings 21 and 22 are formed on the surface of the glass plate 12. For example, the reflectivity of the reflection coating 21 is about 95%, and the reflectivity of the reflection coating 22 is about 100%. An incident window 23 is formed on the surface of the glass plate 12. The reflectivity of the incident window 23 is nearly 0%.

[0020]

The input light 31 converges along a focal line 32 through the incident window 23 using the cylindrical lens 11, and

multiple reflection occurs between the reflection coating 21 and 22. The width of the focal line 32 is referred to as a beam waist of the input light 31. There is a small inclination angle θ between an optical axis 33 of the input light 31 and a normal 34 of the glass plate 12.

[0021]

At the first reflection on the reflection coating 21, 5% of the light passes through the reflection coating 21, and diverges after the beam waist. In addition, 95% of the light is reflected toward the reflection coating 22. After the light is reflected by the reflection coating 22, it reaches again the reflection coating 21 with its position shifted by the distance of d. Then, 5% of the light passes through the reflection coating 21. By repeating the above mentioned reflection and transmission, the light is split into a number of paths which have a constant displacement d.

[0022]

The beam at each path diverges from a virtual image 35 of the beam waist. The virtual images 35 are positioned at constant intervals of 2t along the normal 34. The beams from the virtual images 35 interfere each other, and form collimated light 36 propagated in different directions depending on the wavelength of the input light 31, thereby generating angular dispersion which depends on the wavelength.

[0023]

The displacement of optical paths is expressed by $d = 2t \cdot \sin\theta$, and the difference between path lengths of adjacent beams is computed by $2t \cdot \cos\theta$. The angular dispersion is proportional to the rate of these two values, that is, $\cot\theta$. As a result, the VIPA generates considerably large angular dispersion. As clearly shown in FIG. 2, the term "VIPA" is generated from the array of the virtual images 35.

[0024]

FIG. 3 shows an example of a VIPA type compensator using the VIPA. The compensator shown in FIG. 3 comprises, in

addition to the cylindrical lens 11 and the glass plate 12, a circulator 41, lenses 42 and 43, and a mirror 44.

[0025]

The circulator 41 receives input light from an input fiber 51, and provides the light for the lens 42. The input light is collimated by the lens 42, passes through the cylindrical lens 11, and is focused onto a line on the glass plate 12. After the light passes through the glass plate 12, it is focused onto the mirror 44 through the lens 43, reflected by the mirror 44, and then returned to the glass plate 12 through the lens 43.

[0026]

After the light has been returned to the glass plate 12, it is multiple-reflected in the glass plate 12, and is output from the incident window 23 shown in FIG. 2. The output light is received by the circulator 41 through the cylindrical lens 11 and the lens 42, and is output to an output fiber 52.

[0027]

Thus, the light input to the VIPA is output from the VIPA, reflected by the mirror 44, and returned to the VIPA. The light reflected by the mirror 44 passes in the opposite direction of the path. Since the different wavelength elements of the light have respective focal points at different points on the mirror 44, they pass along different distances, thereby generating wavelength dispersion.

[0028]

If the thickness t of the glass plate 12 is appropriately adjusted, substantially equal dispersion can be assigned to a number of channel wavelengths of the WDM optical transmission system. In addition, the amount of dispersion can be variable by mechanically changing the relative positional relation between the glass plate 12 and the set of the lens 43 and the mirror 44. The configuration of the VIPA type compensator shown in FIG. 3 is only an example, and many other configurations of the VIPA type compensator can be applied to the present embodiment.

[0029]

Since a VIPA type compensator can have variable wavelength dispersion to be applied to input light in the range of, for example, ±5000 ps/nm, the amount of compensation can be correctly set depending on the wavelength dispersion of a line fiber. However, the VIPA type compensator cannot compensate for the dispersion slope of the line fiber.

[0030]

Then, the dispersion slope of the line fiber is compensated for using the DCF, and the difference between the wavelength dispersion of the line fiber and the amount of the dispersion compensation of the DCF is compensated for using a VIPA type compensator, thereby reducing a setting error in the amount of compensation of the wavelength dispersion.

[0031]

If the dispersion slope cannot be sufficiently compensated for by a DCF of the length corresponding to the wavelength dispersion of a line fiber, then the length of the DCF is set long enough corresponding to the dispersion slope of the line fiber. Then, the excess wavelength dispersion of the DCF is inversely compensated for by a VIPA type compensator. Thus, the amount of compensation of the wavelength dispersion and the dispersion slope can be more correctly adjusted to the line fiber.

[0032]

FIG. 4 shows the ideal dispersion compensation for a typical line fiber. In a shape 61 of the wavelength dispersion of a line fiber, the wavelength dispersion has a positive value, and becomes larger as the wavelength gets longer. A shape 62 indicates the wavelength dispersion of an ideal dispersion compensator for completely compensating for the wavelength dispersion, and is symmetrical to the shape 61 with respect to the straight line on which the wavelength dispersion equals zero. The amount of the dispersion compensation of the shape 62 has a negative value, and becomes smaller as the wavelength gets

longer.

[0033]

On the other hand, the shapes of the wavelength dispersion of the typical DCF and the VIPA type compensator are shown in FIGS. 5 and 6, respectively. For the DCF as shown in FIG. 5, the shape of the wavelength dispersion has a negative inclination. However, for the VIPA type compensator shown in FIG. 6, it is substantially flat.

[0034]

FIG. 7 shows the wavelength dependence of the wavelength dispersion of a normal single mode fiber (SMF) line fiber (1.3 μm zero-dispersion fiber). In FIG. 7, a shape 71 indicates the wavelength dispersion of the SMF line fiber, and a shape 72 indicates the wavelength dispersion of a corresponding ideal dispersion compensator. A shape 73 of a broken line indicates the wavelength dispersion of a corresponding DCF.

[0035]

Thus, in the case of a 1.3 μm zero-dispersion fiber, a dispersion compensation, which is close to that of the ideal dispersion compensator and includes the compensation of the dispersion slope, can be performed by an appropriate DCF. The amount of the dispersion compensation can be closer to the shape 72 by combining the DCF with the VIPA type compensator.

[0036]

FIG. 8 shows the wavelength dependence of the wavelength dispersion of a non-zero-dispersion shifted fiber (NZ-DSF) line fiber. In FIG. 8, a shape 81 indicates the wavelength dispersion of the NZ-DSF line fiber, and a shape 82 indicates the wavelength dispersion of a corresponding ideal dispersion compensator. A shape 83 of a broken line indicates the wavelength dispersion of a corresponding DCF.

[0037]

Thus, in the case of the NZ-DSF line fiber, the dispersion slope cannot be sufficiently compensated for using the DCF with a part of dispersion remaining. However, if the DCF are

combined with the VIPA type compensator, for example, the wavelength dispersion of a shape 84 can be obtained, and the amount of the dispersion compensation can be close to the shape 82.

[0038]

By referring to FIGS. 9 through 13, the configuration of the dispersion compensation apparatus obtained by combining a DCF with a VIPA type compensator is described below in detail.

FIG. 9 shows a basic dispersion compensation apparatus. The dispersion compensation apparatus shown in FIG. 9 comprises an input terminal 91, a VIPA type compensator 92, a DCF 93, and an output terminal 94, and is provided at an appropriate position in the optical transmission system including a transmission device and a reception device. Signal light is input from the input terminal 91, passes through the VIPA type compensator 92 and the DCF 93, and is output from the output terminal 94. Thus, the dispersion slope of a line fiber is compensated for by the DCF 93, and the portion of the dispersion characteristic independent of the wavelength is compensated for by the VIPA type compensator 92. The order of the VIPA type compensator 92 and the DCF 93 can be changed.

[0039]

A process of performing the dispersion compensation can be selected from the following two processes, depending on whether or not the DCF 93 can completely compensate for the dispersion slope of the line fiber.

(1) A case where the dispersion slope of the DCF 93 is sufficiently large when it is compared with the dispersion slope of the line fiber

For example, if a normal SMF line fiber of 600 km is used, the characteristic of the dispersion compensation by a dispersion compensation apparatus is as shown in FIG. 10. In FIG. 10, a shape 101 indicates the wavelength dispersion of a line fiber, a shape 102 indicates the wavelength dispersion of the DCF 93, and a shape 103 indicates the wavelength dispersion

of the VIPA type compensator 92.

[0040]

In this case, since the wavelength dispersion and the dispersion slope of the DCF 93 substantially completely cancel the wavelength dispersion and the dispersion slope of the line fiber, a flat characteristic as a shape 104 can be obtained by adding up the wavelength dispersion of the line fiber and the DCF 93. If the wavelength dispersion of the VIPA type compensator 92 is added to the above mentioned characteristic, then the characteristic of a shape 105 can be obtained, and the wavelength dispersion and the dispersion slope can be substantially 0. In this case, the VIPA type compensator 92 adds negative wavelength dispersion.

(2) A case where the dispersion slope of the DCF 93 is insufficient as compared with the dispersion slope of a line fiber

For example, if a normal NZ-DSF line fiber of 600 km is used, the characteristic of the dispersion compensation by a dispersion compensation apparatus is as shown in FIG. 11. In FIG. 11, a shape 111 indicates the wavelength dispersion of a line fiber, and a shape 112 indicates the wavelength dispersion of the DCF 93 when the absolute value of the wavelength dispersion of the DCF 93 matches the wavelength dispersion of the line fiber. A shape 113 indicates the wavelength dispersion of the DCF 93 when the dispersion slope of the DCF 93 matches the dispersion slope of the line fiber. A shape 114 indicates the wavelength dispersion of the VIPA type compensator 92.

[0041]

In this case, when the wavelength dispersion of line fiber and the wavelength dispersion of the DCF of the shape 112 are added up, the characteristic of a shape 115 is obtained and dispersion slope of the line fiber cannot be canceled.

[0042]

Therefore, using the DCF having the characteristic of the shape 113, the wavelength dispersion of the line fiber and the

wavelength dispersion of the shape 113 are added up. As a result, a flat characteristic as a shape 116 can be obtained. When the wavelength dispersion of the VIPA type compensator 92 is furthermore added to the characteristic, the characteristic of shape 117 can be obtained, thereby setting both wavelength dispersion and dispersion slope to substantially zero. In this process (2), unlike in the process (1), the VIPA type compensator 92 adds the positive wavelength dispersion.

[0043]

Assume that, as a practical example of the process (1), above, a normal 1.3 μm zero-dispersion fiber having the following characteristic with a wavelength λ is used as a line fiber.

wavelength dispersion: +16.5 ps/nm/km (λ = 1550 nm)
dispersion slope: +0.055 ps/nm^2/km (λ = 1550 nm)

In this case, for example, the DCF having the following characteristic is used.

wavelength dispersion: -80 ps/nm/km (λ = 1550 nm)
dispersion slope: -0.3 ps/nm^2/km (λ = 1550 nm)

The wavelength dispersion of the above mentioned line fiber (100 km) is +16.5 × 100 = +1650 ps/nm (λ = 1550 nm), and the dispersion slope is +0.055 × 100 = +5.5 ps/nm^2 (λ = 1550 nm). Therefore, the length of the DCF required to completely remove the dispersion slope is 5.5/0.3 = 18.3 (km).

[0044]

At this time, since the wavelength dispersion of the DCF is -80 × 18.3 = -1464 (ps/nm), the wavelength dispersion of +1650 - 1464 = +186 (ps/nm) remains. Therefore, if the wavelength dispersion of the VIPA type compensator is adjusted to be set to -186 ps/nm, both wavelength dispersion and dispersion slope can be removed.

[0045]

Furthermore, assume that, as a practical example of the process (2), above, a normal NZ-DSF having the following characteristic with a wavelength λ is used as a line fiber.

wavelength dispersion: +4.3 ps/nm/km (λ = 1550 nm)

dispersion slope: +0.04 ps/nm^2/km (λ = 1550 nm)

In this case, for example, as in the process (1) above, the DCF having the following characteristic is used.

wavelength dispersion: -80 ps/nm/km (λ = 1550 nm)

dispersion slope: -0.3 ps/nm^2/km (λ = 1550 nm)

The wavelength dispersion of the above mentioned line fiber (100 km) is +4.3 × 100 = +430 ps/nm (λ = 1550 nm), and the dispersion slope is +0.04 × 100 = +4.0 ps/nm^2 (λ = 1550 nm). Therefore, the length of the DCF required to completely remove the dispersion slope is 4.0/0.3 = 13.3 (km).

[0046]

At this time, since the wavelength dispersion of the DCF is -80 × 13.3 = -1064 (ps/nm), the wavelength dispersion of +430 - 1064 = -634 (ps/nm) remains. Therefore, if the wavelength dispersion of the VIPA type compensator is adjusted to be set to +634 ps/nm, both wavelength dispersion and dispersion slope can be removed.

[0047]

As described above, since the variable range of the amount of the dispersion compensation of the VIPA type compensator is very wide, a configuration for the dispersion compensation of the whole optical transmission system can be adopted using the characteristic of the variable range.

[0048]

FIG. 12 shows an example of the above mentioned optical transmission system. The optical transmission system shown in

FIG. 12 comprises a transmission device 121, one or more relay devices 122, a reception device 123, and line fibers 124 connecting these devices. The transmission device 121 comprises a transmitter 131 and the DCF 132, the relay device 122 comprises the DCF 132, and the reception device 123 comprises the VIPA type compensator 133 and a receiver 134. Thus, the DCF 132 is provided for the transmission device 121 and each of the relay devices 122, and the VIPA type compensator 133 is provided for the reception device 123.

[0049]

Assume that a normal 1.3 μm zero-dispersion fiber having the following characteristic with a wavelength λ is used as the line fiber 124, and the DCF having the above mentioned characteristic is used as the DCF 132.

wavelength dispersion: +16.5 ± 0.5 ps/nm/km (λ = 1550 nm)

dispersion slope: +0.055 ps/nm^2/km (λ = 1550 nm)

Assuming that the number of the relay devices 122 is three, and four spans (stages) of the 100 km line fibers 124 are used, the length of the DCF per span required to compensate for a dispersion slope is 18.3 km as described above.

[0050]

In addition, since the wavelength dispersion of four spans of line fibers is +16.5 ± 0.5 × 100 × 4 = +6600 ± 200 ps/nm (λ = 1550 nm), and the wavelength dispersion of four spans of the DCFs is -80 × 18.3 × 4 = -5856 (ps/nm), the wavelength dispersion of +6600 ± 200 - 5856 = +744 ± 200 (ps/nm) remains. Therefore, if the wavelength dispersion of the VIPA type compensator is adjusted to be set to −744 ± 200 ps/nm, then the wavelength dispersion and the dispersion slope can be correctly compensated for.

[0051]

Thus, when the NZ-DSF having the above mentioned characteristic is used as the line fiber 124, the length of the

DCF per span required to compensate for a dispersion slope is 13.3 km as described above.

[0052]

In addition, since the wavelength dispersion of four spans of line fibers is +4.3 × 100 × 4 = +1720 ps/nm (λ = 1550 nm), and the wavelength dispersion of four spans of the DCFs is -80 × 13.3 × 4 = -4256 (ps/nm), the wavelength dispersion of +1720 - 4256 = -2536 (ps/nm) remains. Therefore, if the wavelength dispersion of the VIPA type compensator is adjusted to be set to +2536 ps/nm, then both wavelength dispersion and dispersion slope can be removed.

[0053]

In this case, however, a large amount of wavelength dispersion has been accumulated before the signal light reaches the reception device from the transmission device, which is not desired. Therefore, instead of canceling the dispersion slope of the line fiber by the DCF, it is considered to adjust the length of the DCF such that the wavelength dispersion of the line fiber can be canceled.

[0054]

Since the wavelength dispersion per span of the above mentioned line fiber is +430 ps/nm (λ = 1550 nm), the length of the DCF required to completely remove the wavelength dispersion is 430/80 = 5.4 (km). Therefore, the length of the DCF per span is set to 5.4 km, and the wavelength dispersion of the VIPA type compensator is adjusted to 0 ps/nm, thereby removing the wavelength dispersion. However, in this case, the dispersion slope cannot be completely removed.

[0055]

If the length of the DCF per span is not changed depending on the length of the line fiber, the dispersion slope of the 5.4 km DCF is -0.3 × 5.4 = 1.62 (ps/nm^2). Therefore, when the length of the line fiber per span is 1.62/0.04 = 40.5 (km), the dispersion slope can be completely removed.

[0056]

At this time, since the wavelength dispersion of four spans of line fibers is $+4.3 \times 40.5 \times 4 = 697$ ps/nm ($\lambda = 1550$ nm), and the wavelength dispersion of four spans of the DCFs is $-80 \times 5.4 \times 4 = -1728$ (ps/nm), the wavelength dispersion of $+697 - 1728 = -1031$ (ps/nm) remains. Therefore, if the wavelength dispersion of the VIPA type compensator is adjusted to be set to +1031 ps/nm, then both wavelength dispersion and dispersion slope can be removed.

[0057]

FIG. 13 shows an example of the configuration of the reception device 123 shown in FIG. 12. The reception device shown in FIG. 13 comprises the VIPA type compensator 133, the receiver 134, and an error detector 141. The receiver 134 comprises a WDM coupler 142 and a plurality of optical-to-electrical transducers 143.

[0058]

The WDM coupler 142 branches signal light output from the VIPA type compensator 133, and the optical-to-electrical transducer 143 converts the optical signal into an electric signal. The error detector 141 detects an error in the electric signal, and outputs a control signal to the VIPA type compensator 133. According to the control signal, the wavelength dispersion of the VIPA type compensator 133 is adjusted such that the wavelength dispersion of the signal light can be compensated for. Thus, a transmission device and a relay device are provided with a DCF, and a VIPA type compensator is provided only for the reception device, thereby easily adjusting the amount of dispersion compensation.

[0059]

According to the above mentioned embodiment, the characteristic of only the VIPA type compensator 133 is variable. However, the characteristic of a DCF can also be variable. FIG. 14 shows such a variable DCF compensator. The compensator shown in FIG. 14 comprises an input terminal 151, a DCF switch unit 152, and an output terminal 153.

[0060]

The DCF switch unit 152 comprises three DCFs 161, 162, and 163 having different characteristics, and can select any of them. Thus, it is possible to switch the DCFs depending on the characteristic of a line fiber, and signal light input from the input terminal 151 is output from the output terminal 153 through a selected DCF.

[0061]

The wavelength dispersion and the dispersion slope per unit length of the DCFs 161, 162, and 163 can be either identical or different. When they are identical, three DCFs having different characteristics can be obtained by changing the length of each DCF.

[0062]

By combining a variable DCF compensator with a VIPA type compensator, a dispersion compensation apparatus capable of adjusting both wavelength dispersion and dispersion slope can be realized.

The wavelength dispersion of a DCF is not limited to a negative value, but can be a positive value. For example, as shown in FIG. 15, assume that a DCF having positive wavelength dispersion of a shape 172 is used for a line fiber having wavelength dispersion of a shape 171. In this case, a VIPA type compensator having negative wavelength dispersion of a shape 173 can be used.

[0063]

In addition, the wavelength dispersion of a line fiber is not limited to a positive value, but can be a negative value. When the wavelength dispersion of a line fiber has a negative value, the sign of the wavelength dispersion of the dispersion compensator can be inverted in the above mentioned embodiment.

[0064]

In addition, the dispersion slope of a line fiber is not limited to a positive value, but can be a negative value. For example, as shown in FIG. 16, for a line fiber having a negative

dispersion slope of a shape 181, a DCF having a positive dispersion slope of a shape 182 and a VIPA type compensator having wavelength dispersion of a shape 183 can be used.

[0065]

Furthermore, it is not necessary to always use a DCF and a VIPA type compensator as first and second compensators, but any two types of compensators having different characteristics about wavelength dispersion can be used. For example, a grating type compensator using fiber grating can be a substitute for a DCF or a VIPA type compensator.

[0066]

[Effect of the Invention]

According to the present invention, the wavelength dispersion and the dispersion slope of a line fiber can be collectively compensated for by combining two types of dispersion compensators having different characteristics. Furthermore, depending on the uneven wavelength dispersion and dispersion slope of a line fiber, the characteristic of a dispersion compensation apparatus can be variable, thereby reducing setting errors in the amount of compensation.

[Brief Description of the Drawings]

FIG. 1 shows a principle of a dispersion compensation apparatus according to the present invention.

FIG. 2 shows a virtually imaged phased array (VIPA).

FIG. 3 shows a VIPA type compensator.

FIG. 4 shows an ideal dispersion compensation.

FIG. 5 shows the dispersion compensation by a dispersion compensation fiber (DCF).

FIG. 6 shows the dispersion compensation by a VIPA type compensator.

FIG. 7 shows the wavelength dispersion of a single mode fiber (SMF) line fiber.

FIG. 8 shows the wavelength dispersion of a non-zero dispersion shifted fiber (NZ-DSF) line fiber.

FIG. 9 shows a dispersion compensation apparatus.

FIG. 10 shows the dispersion compensation of an SMF line fiber.

FIG. 11 shows the dispersion compensation of an NZ-DSF line fiber.

FIG. 12 shows an optical transmission system.

FIG. 13 shows a reception device.

FIG. 14 shows a variable dispersion compensation fiber (DCF) compensator.

FIG. 15 shows the case in which the wavelength dispersion of a DCF is positive.

FIG. 16 shows the case in which the dispersion slope of a line fiber is negative.

[Explanation of the Codes]

1 and 2 Compensation means
11 Cylindrical lens
12 Glass plate
21 and 22 Reflection coatings
23 Incident window
31 Input light
32 Focal line
33 Optical axis
34 Normal
35 Virtual image
36 Collimated light
41 Circulator
42 and 43 Lenses
44 Mirror
51 Input fiber
52 Output fiber
91 and 151 Input terminals
92 and 133 VIPA type compensators
93, 132, 161, 162, and 163 DCFs
94 and 153 Output terminals
121 Transmission device
122 Relay device

123 Reception device

131 Transmitter

134 Receiver

141 Error detector

142 WDM coupler

143 Optical-to-electrical transducer

152 DCF switch unit

61, 62, 71, 72, 73, 81, 82, 83, 84, 101, 102, 103, 104, 111, 112, 113, 114, 115, 116, 117, 171, 172, 173, 181, 182, and 183 Shapes of wavelength dispersion

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OCT 26 2006
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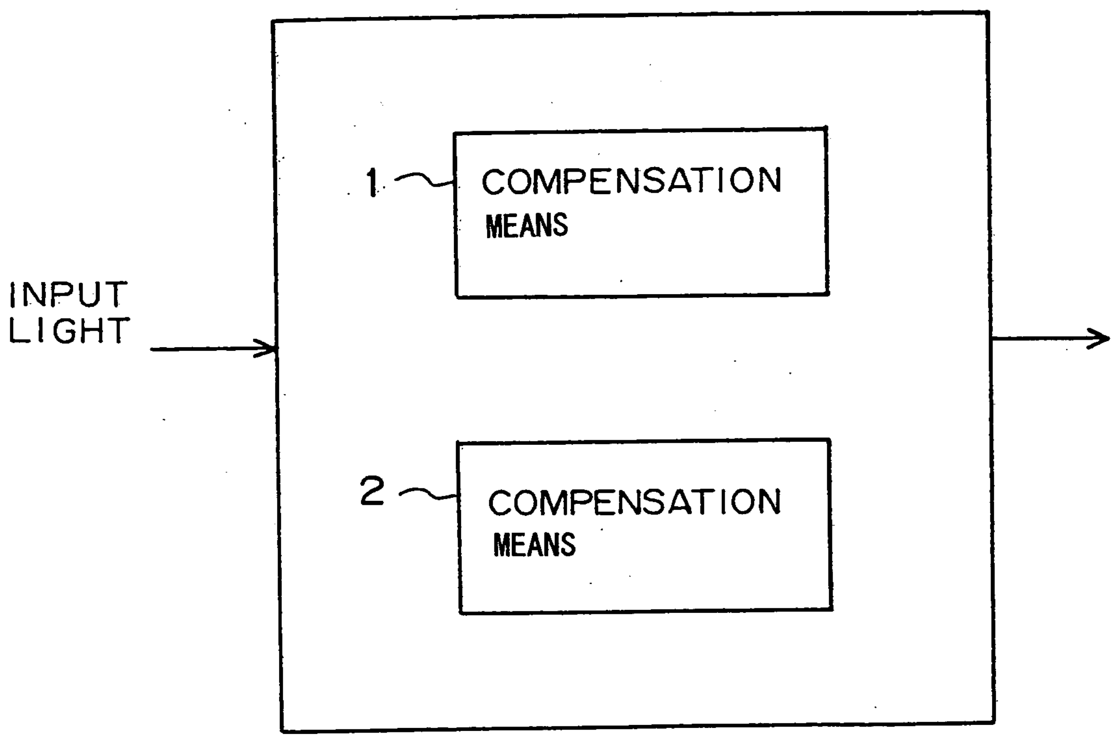
[Document Name] Drawings

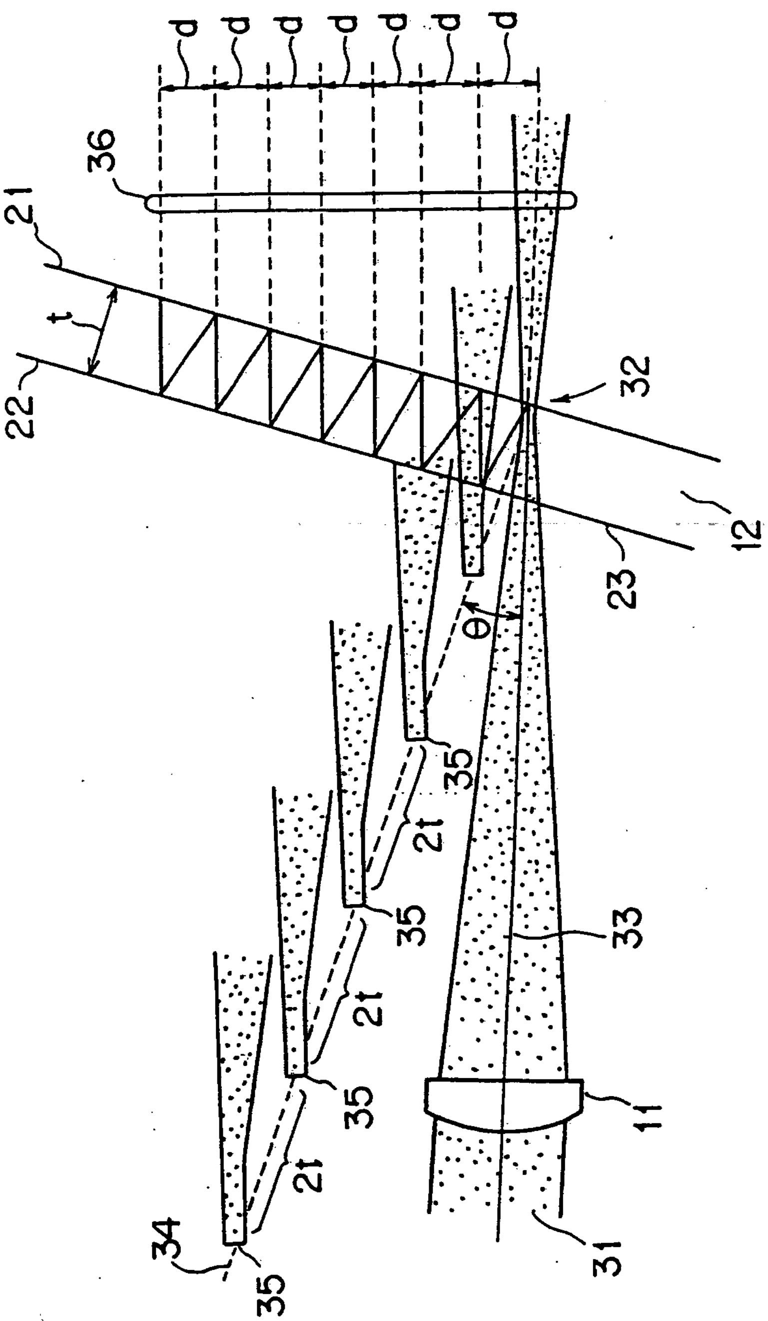
[FIG. 1]

Diagram showing a principle of the present invention



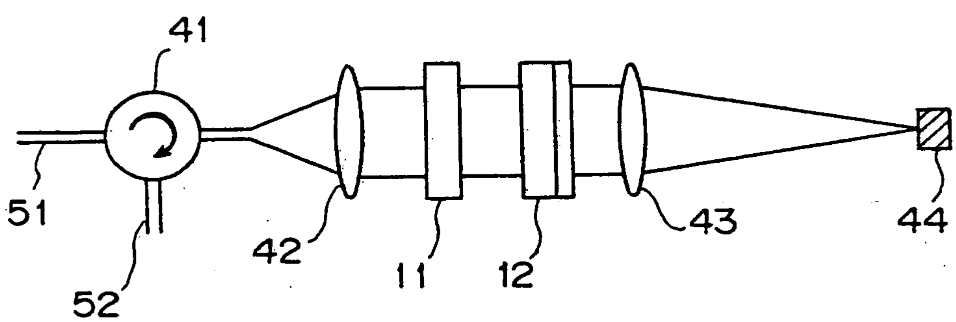
[FIG. 2]

Diagram showing a VIPA



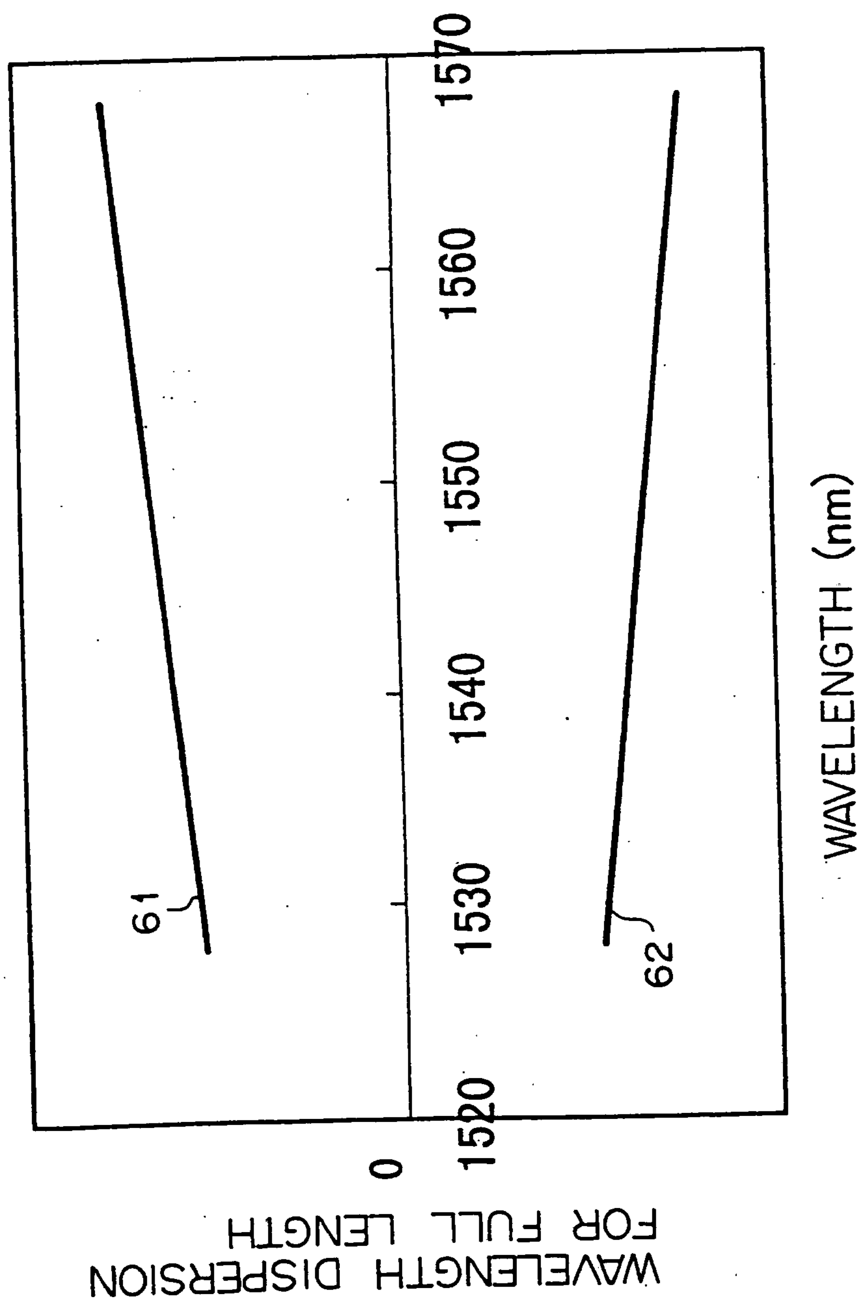
[FIG. 3]

Diagram showing a VIPA type compensator



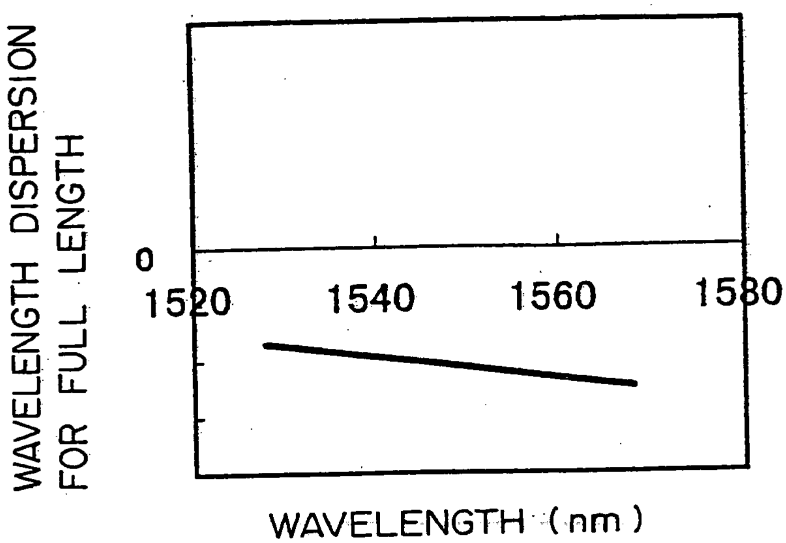
[FIG. 4]

Diagram showing an ideal dispersion compensation



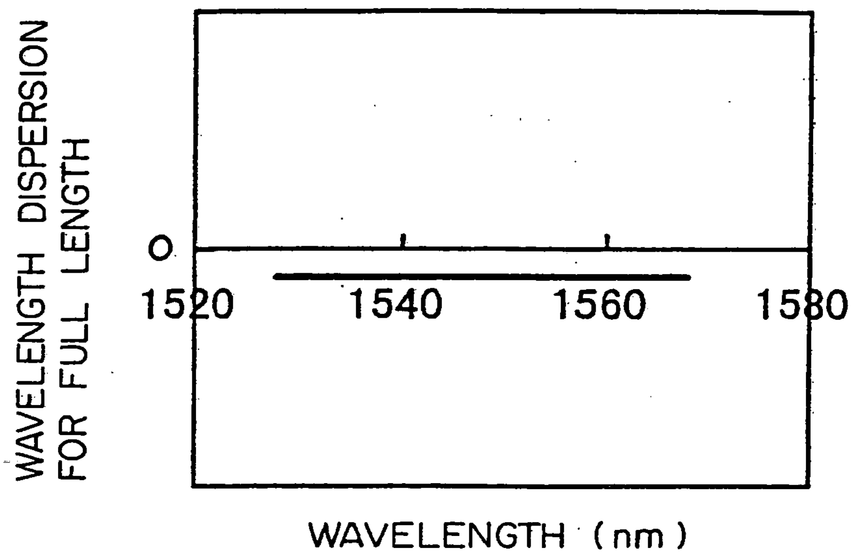
[FIG. 5]

Diagram showing the dispersion compensation by a DCF



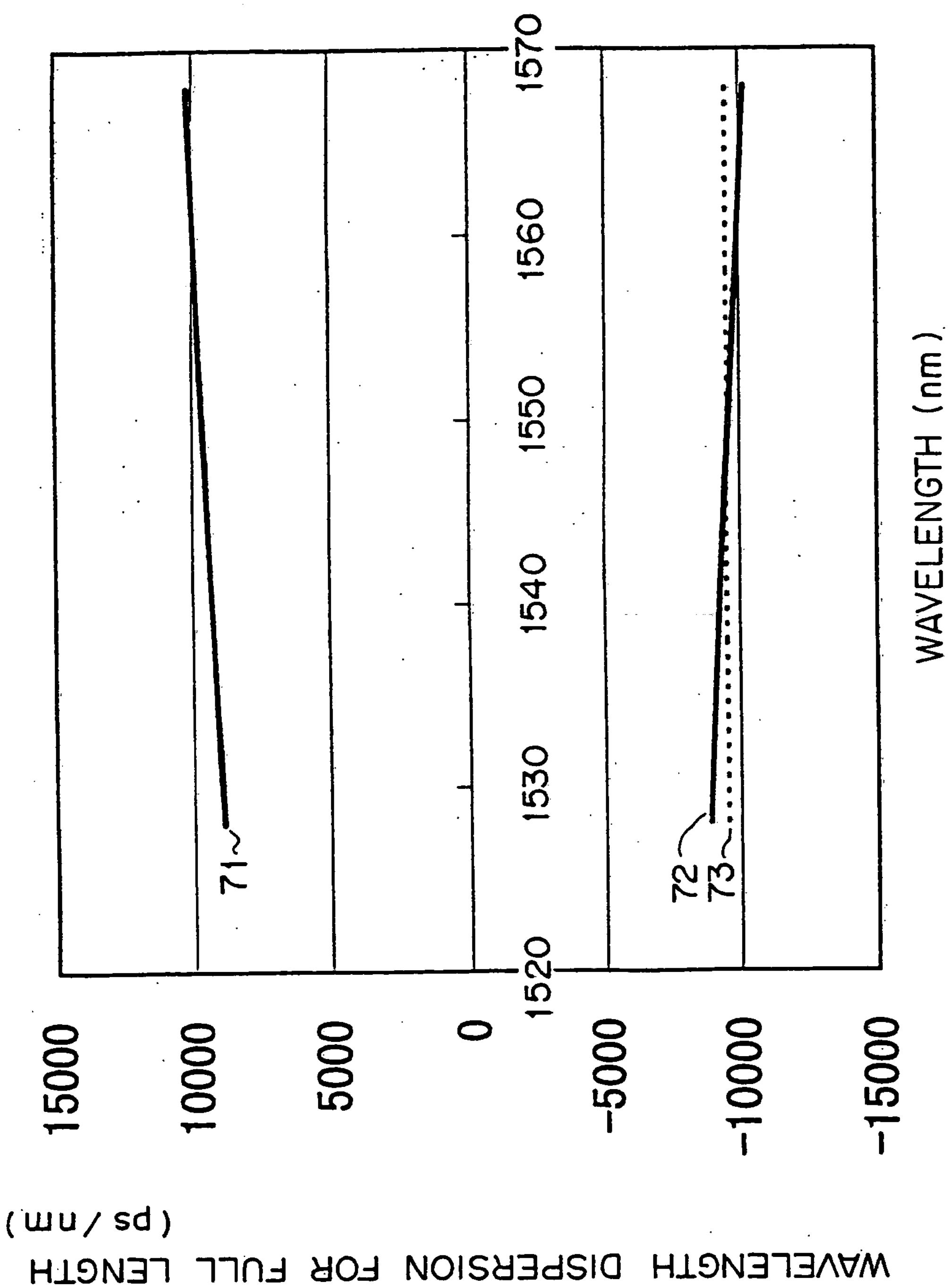
[FIG. 6]

Diagram showing the dispersion compensation by a VIPA type compensator



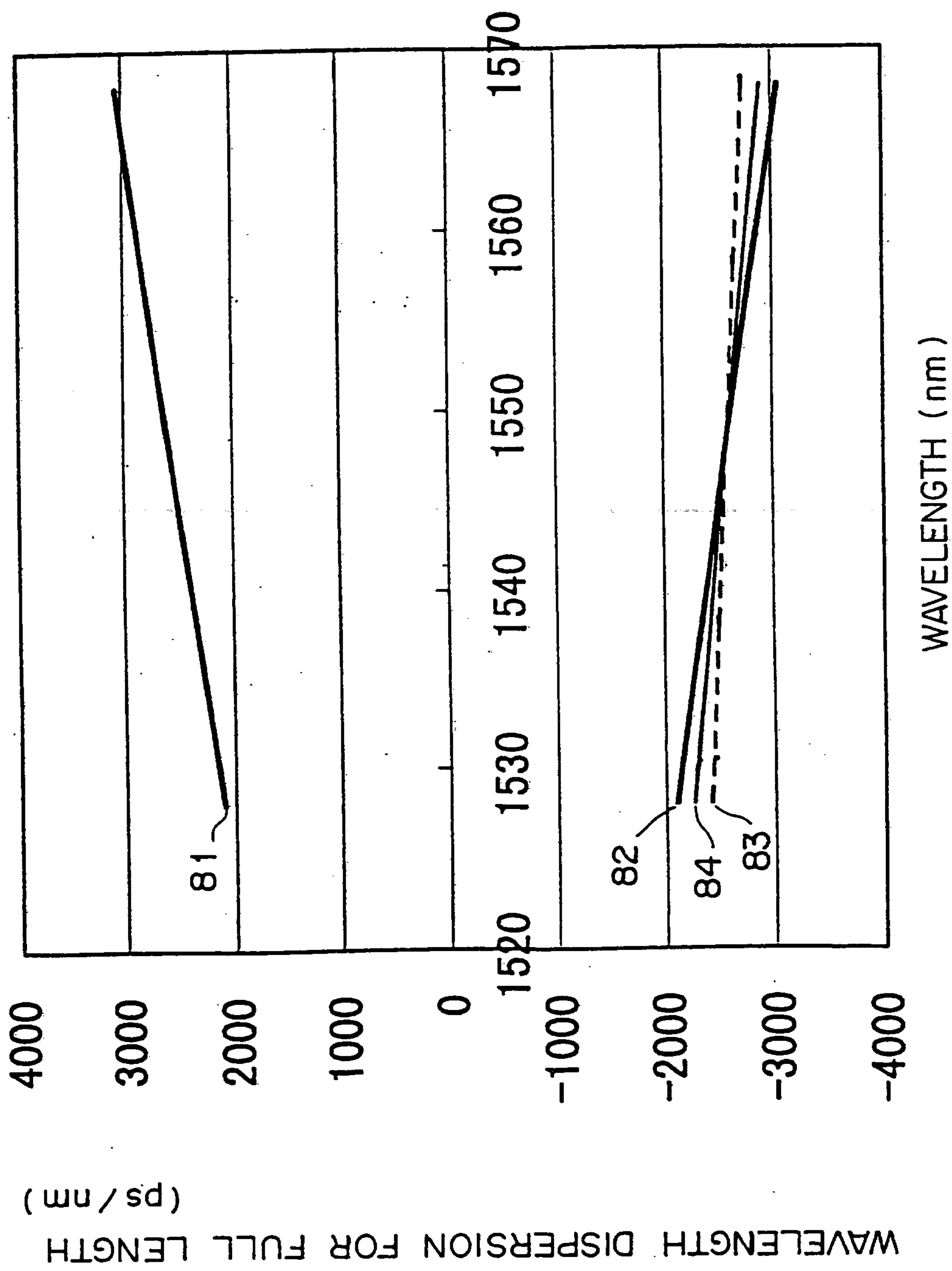
[FIG. 7]

Diagram showing the wavelength dispersion of an SMF line fiber



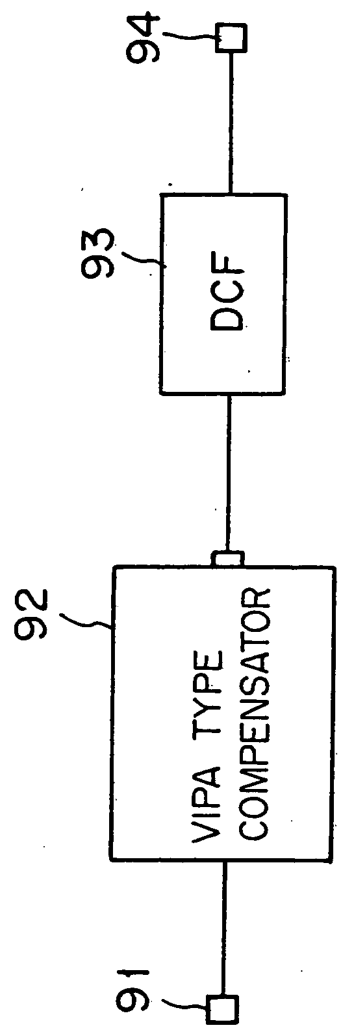
[FIG. 8]

Diagram showing the wavelength dispersion of an NZ-DSF line fiber



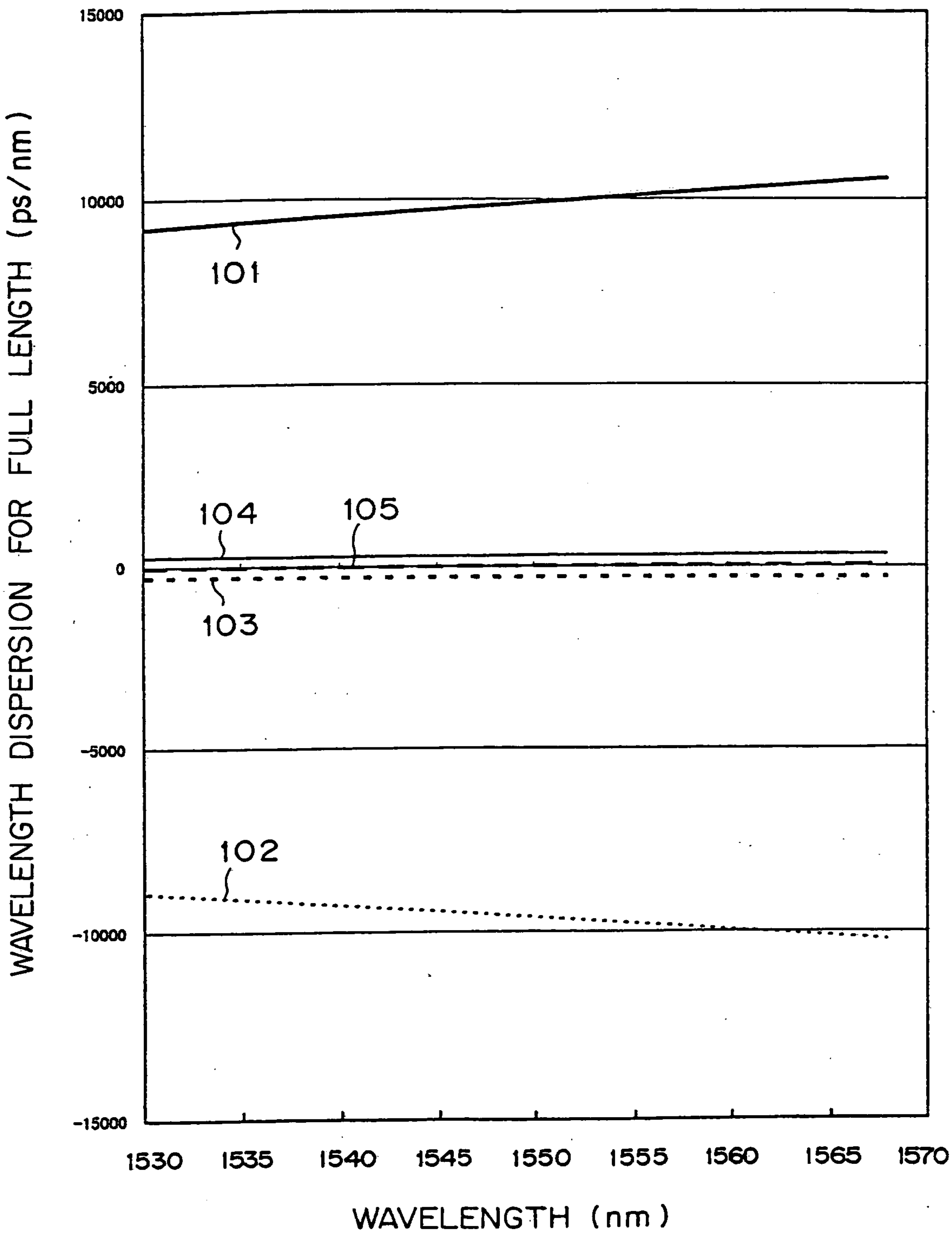
[FIG. 9]

Diagram showing a dispersion compensation apparatus



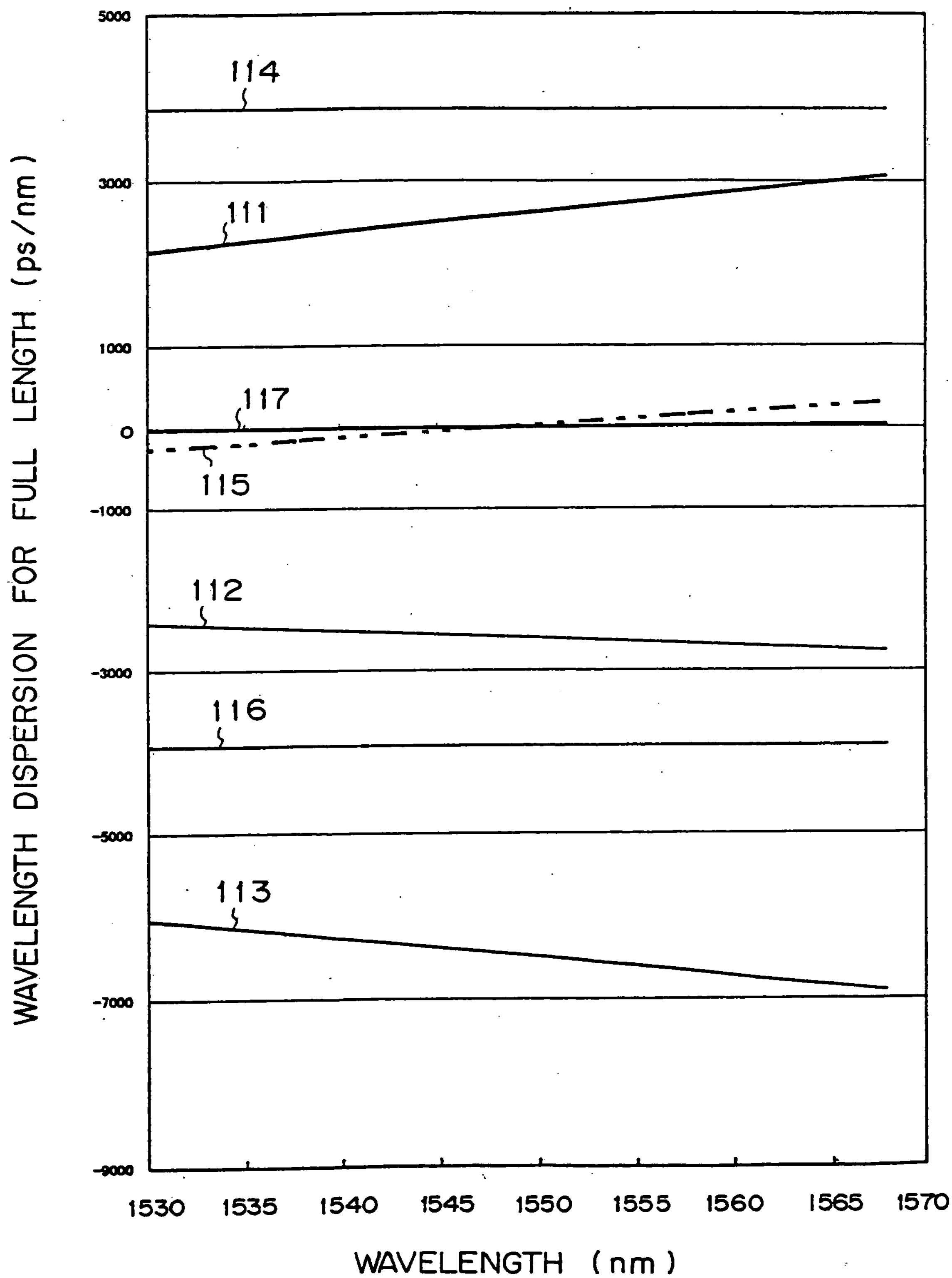
[FIG. 10]

Diagram showing the dispersion compensation of an SMF line fiber



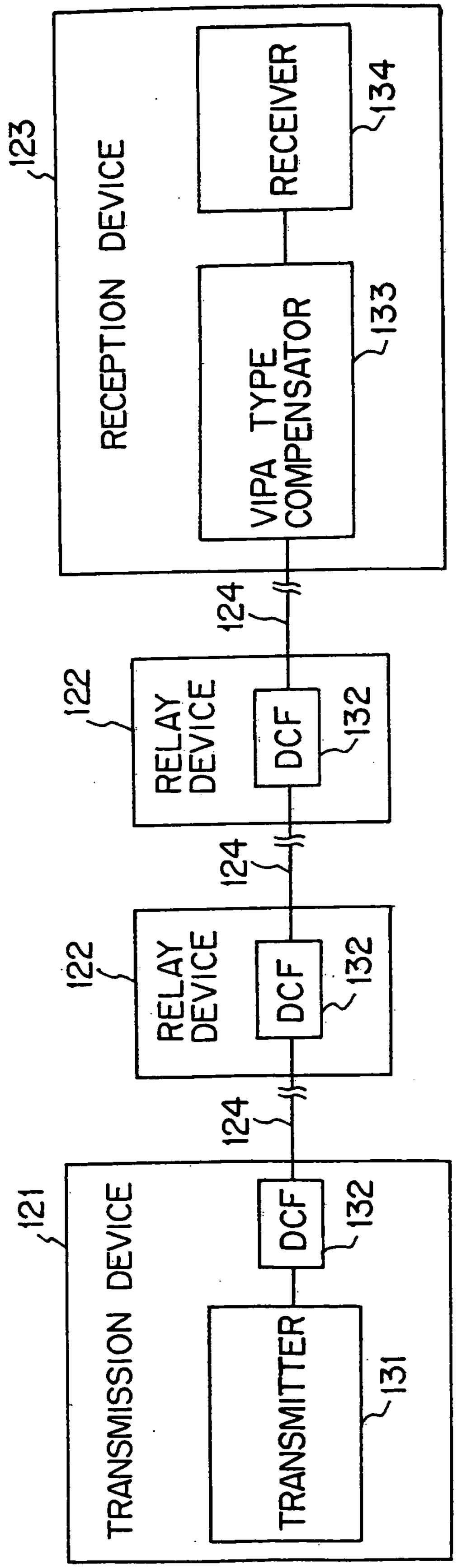
[FIG. 11]

Diagram showing the dispersion compensation of an NZ-DSF line fiber



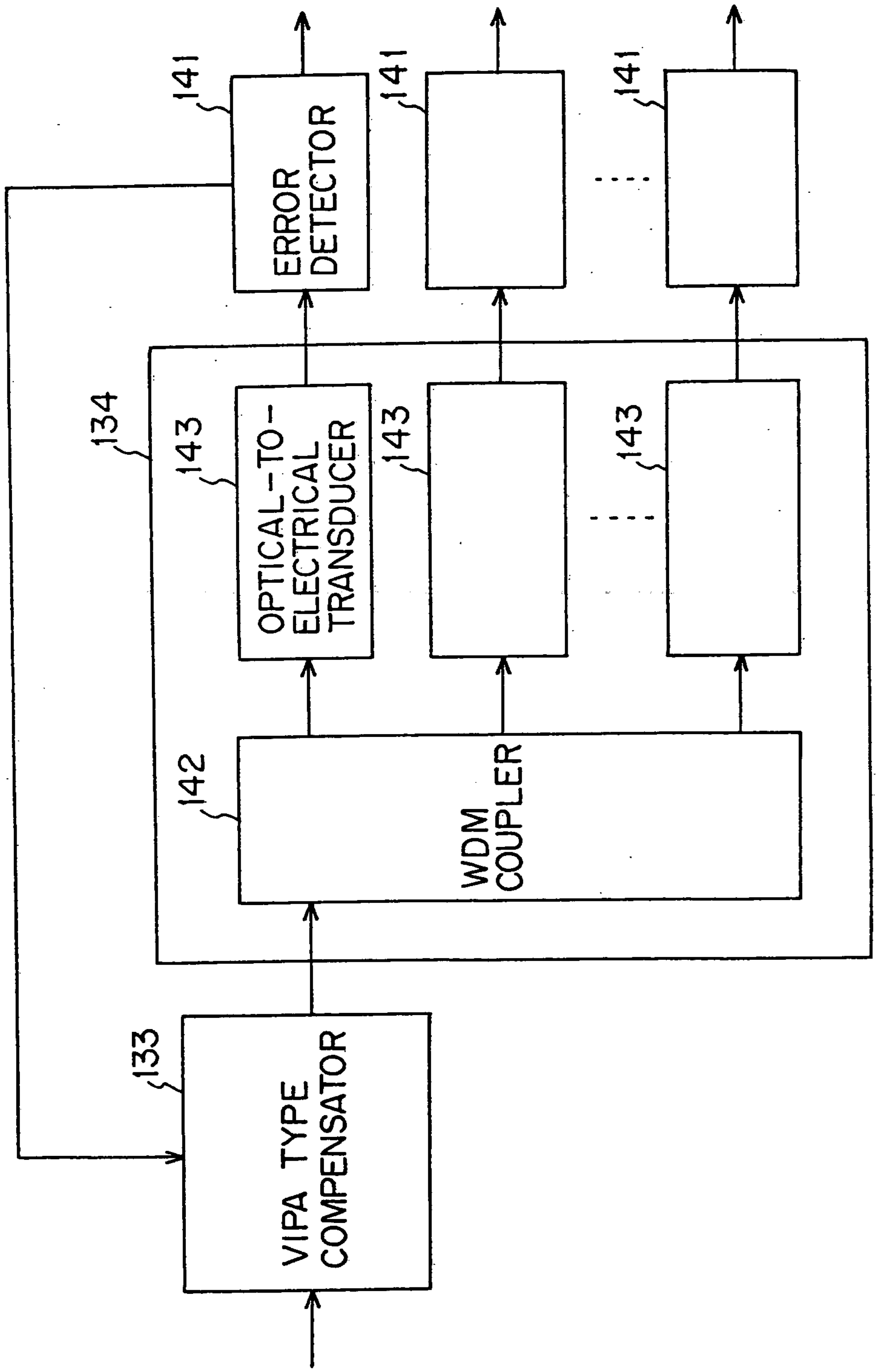
[FIG. 12]

Diagram showing an optical transmission system



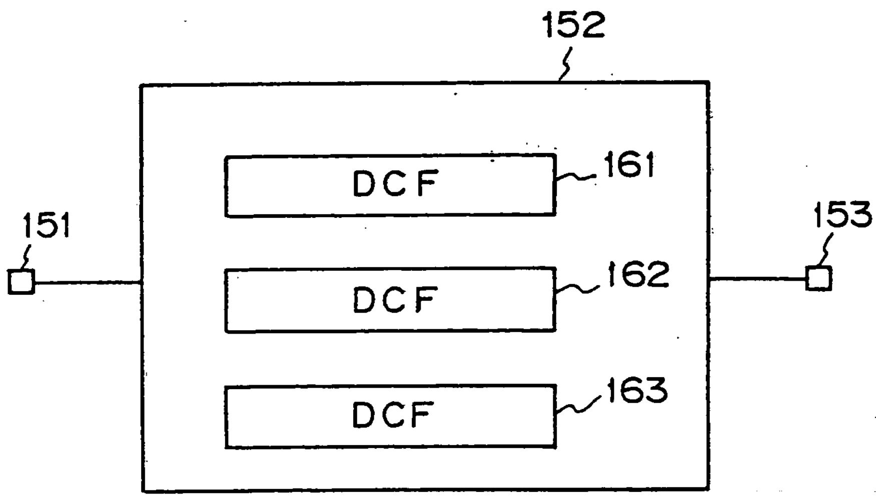
[FIG. 13]

Diagram showing a reception device



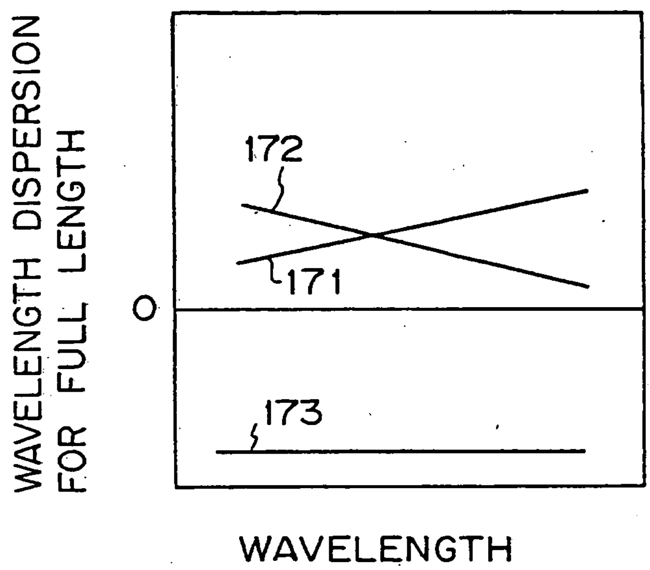
[FIG. 14]

Diagram showing a variable DCF compensator



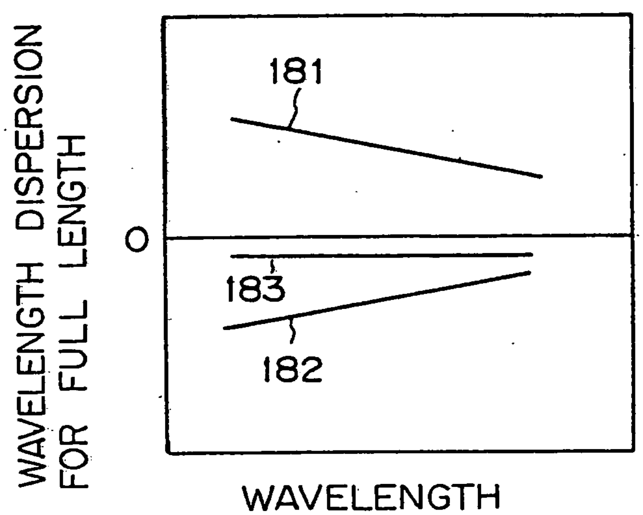
[FIG. 15]

Diagram showing the case in which the wavelength dispersion of a DCF is positive



[FIG. 16]

Diagram showing the case in which the dispersion slope of a line fiber is negative



[Document Name] Abstract

[Abstract]

[Object] It is an object of the present invention to compensate for wavelength dispersion and dispersion slope of a line fiber, and to reduce the setting error of the amount of the compensation of wavelength dispersion in a wavelength division multiplexing optical transmission system.

[Means for Solving the Problems] The dispersion slope of a characteristic 101 of a line fiber is cancelled by the dispersion slope of a characteristic 102 of a fiber type compensator, and a flat characteristic 104 can be obtained by adding up these characteristics. If a characteristic of a virtually imaged phased array type compensator is set as 103 and added to the characteristic 104, then the characteristic 105 can be obtained, and the wavelength dispersion and the dispersion slope can be substantially 0.

[Selected Drawing] FIG. 10